

III. Session 3: Space Shuttle Propulsion System Reliability

A. External Tank (ET) System Reliability and Lessons – K. Welzyn

The External Tank exhibited structural efficiency and met propulsion performance goals throughout the 30 year flight program. Reliability of the structural, propulsion, electrical, thermal protection subsystems were excellent. Process controls were implemented to assure cleanliness in the production environment, to control contaminants, and to preclude corrosion. Each tank was accepted via rigorous inspections, including non-destructive evaluation techniques, proof testing, and all systems testing. In the post STS-107 era, the project focused on ascent debris risk reduction. This was accomplished via stringent process controls, post flight assessment using substantially improved imagery, and selective redesigns. These efforts were supported with a number of test programs to simulate combined environments. Processing improvements included development and use of low spray guns for foam application, additional human factors considerations for production, use of high fidelity mockups during hardware processing with video review, improved tank access, extensive use of non destructive evaluation, and producibility enhancements. Design improvements included redesigned bipod fittings, a bellows heater, a feedline camera active during ascent flight, removal of the protuberance airload ramps, redesigned ice frost ramps, and titanium brackets replaced aluminum brackets on the liquid oxygen feedline. Post flight assessment improved due to significant addition of imagery assets, greatly improving situational awareness. The debris risk was reduced by two orders of magnitude. During this time a major natural disaster was overcome when Katrina damaged the manufacturing facility. Other problems solved included resolution of engine cut off system intermittent anomalies, leakage from the hydrogen vent system interface with the launch pad, and recovery from a severely damaged tank due to a hail storm. Numerous lessons from these efforts are documented within the paper.

B. Space Shuttle Main Engine (SSME), Reliability Validated by a Million Seconds of Testing – K. Van Hooser

The amazing Space Shuttle Main Engine achieved a remarkable flight performance record. All flights were successful with only one mission requiring an ascent abort condition, which still resulted in an acceptable orbit and mission. This was achieved in large part via extensive ground testing to fully characterize performance and to establish acceptable life limits. During the program numerous test stands were utilized for development and operations and over a million seconds of accumulated test and flight time was achieved. Numerous features including fracture control, fleet leader logic, post test data analysis, and evolving of the design contributed to high reliability. At the end of the program the predicted reliability had improved by a factor of three. Post flight inspection and assessment was also a key part of assuring proper performance of the flight hardware. A number of design improvements were innovative and added to reliability including incorporation of an intelligent health management system, a first for liquid rocket engines. Redundancy management was also a key feature of engine system reliability and the main engine controller was a fully redundant digital computer system. Software development and verification was a significant part of the operational program. Additional subsystem redundancy was provided by the hydraulic and pneumatic actuation systems. These unique challenges and features of the space shuttle main engine and the resulting reliability will be discussed in detail in the paper.

C. Reusable Solid Rocket Motor (RSRM) Reliability via Process Control – D. Moore

The reusable solid rocket motor has achieved significant reliability via process control, ground test programs, and post flight assessment. Process control is mandatory for a solid rocket motor as an acceptance test of the delivered product is not feasible. Material fingerprinting was employed to assess any drift in delivered material properties. Process control included process failure modes and effects analysis, statistical process control, witness panels, and process product integrity audits. Material controls and inspections were maintained throughout the sub tier vendors. The RSRM maintained both full scale and sub-scale test articles. These enabled continuous improvement of design and evaluation of process control and material behavior. This also allowed testing of new materials, required sometimes due to obsolescence, to be evaluated prior to flight. Additionally RSRM reliability was achieved through attention to detail in post flight assessment to observe any shift in performance. The post-flight analysis and inspections provided invaluable reliability data as it enables observation of actual flight performance, most of which would not be available if the motors were not recovered. These unique challenges and features of the reusable solid rocket motor and the resulting reliability will be discussed in detail in the paper.

D. Solid Rocket Booster (SRB) Reliability via Acceptance and Testing – D. Wood

The Solid Rocket Booster element achieved reliability via extensive system testing and checkout at each stage of integration, redundancy management, and thorough post flight assessment. Because the booster element is recoverable, subsystems were available for inspection and testing post flight, unique to the Shuttle launch vehicle. Following recovery each system was disassembled and returned to flight inventory. Each unit was retested for acceptability. Problems were noted and corrective actions were implemented as needed. During each phase of assembly and integration extensive acceptance testing was accomplished to identify any change in performance and assure proper function. The SRB provided fully redundant critical systems including thrust vector control, mission critical pyrotechnics, avionics, and parachute recovery system. The design intent was to lift off with full redundancy however on occasion the redundancy management scheme was needed for reliability. And the unique capability to recover and reuse components allowed for evaluation of performance in the flight environment, and implement improvements when needed to assure reliable performance. The post flight assessment process was quite detailed and a significant portion of flight operations. These unique challenges and features of the reusable solid rocket booster element, and the reliability that resulted, will be discussed in detail in the paper.